

Analysis of Maximal Ratio Combining Scheme with IDMA Systems Using Prime Interleaver with Zigzag Coding

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Abstract

In wireless communication, fading is referred to be the major concern for researchers all over the world. For combating fading problem, the antenna diversity is termed to be one of the possible solutions to alleviate the effect of fading over wireless channels, of which the Maximal Ratio Receiver Combining (MRRC) diversity can effectively combat the effect of fading. In this paper, MRRC diversity scheme is used on Prime Interleaver with Zigzag coding, an error-correcting code, described by a highly structured zigzag graph. Due to the structural properties of Zigzag coding, very low-complexity soft-in/soft-out decoding rules can be implemented. In this paper, performance of MRRC diversity is presented in iterative IDMA system using Prime Interleaver with Zigzag coding with one transmit and two receiving antennas. The simulation results demonstrate that IDMA system with Zigzag coding performs better in terms of BER in comparison to other systems.

Keywords

Bit Error Rate; MRRC Scheme; Random Interleaver; Multiuser Detection; Zigzag Coding; Soft -in/Soft-out

Introduction

In wireless systems, fading may occur due to either multipath propagation which is referred to as multipath induced fading, or shadowing from obstacles affecting the wave propagation, sometimes referred to as shadow fading. In general, the term "Fading" is used to describe the rapid fluctuations of the amplitudes, phases or multipath delays of radio signal over a short period of time or travel distance.

Therefore it becomes mandatory to reduce the problem of multi- path fading, but without increase at the cost of extra power or additional bandwidth. One of the effective solutions is termed to be the space diversity (based on orthogonal design) to overcome the problems of additional power or extra bandwidth. The most commonly used Space diversity method employed with IDMA system is known as the

Maximal Ratio Receiver Combining (MRRC) technique, with one transmit and two receiver antennas where several uncorrelated replicas of the signals are combined at the receiver side to improve the signal reconstruction. Maximal Ratio Receiver Combining (MRRC) technique uses multiple receiving antennas and performs certain signal processing mechanism including combining, selecting, and switching mechanisms in order to improve the quality of the received signal.

The performance of CDMA systems, in wireless communication, is mainly limited due to multiple access interference and intersymbol interference. The IDMA scheme is known as advanced version of CDMA scheme, which inherits many advantages from CDMA scheme such as robustness against fading, mitigation of cross-cell interferences, dynamic channel sharing asynchronous transmission, ease in cell planning. Diversity mechanism can be applied to transmitter as well as receiver or both of them. In literature, diversity on both transmitter and receiver ends has been duly employed for combating the problems of fading.

The objective of the paper is to use MRRC diversity in iterative IDMA communication system to reduce the effect of fading with Zigzag coding on Prime Interleaver.

IDMA MODEL

IDMA can be considered as a special case of DS-CDMA. In IDMA, each data stream is firstly encoded by a (very) low-rate encoder. For convenience, each data stream is referred to as layer. The main difference between IDMA and conventional DS-CDMA is that in IDMA each layer is assigned a layer-specific interleaver, whereas in DS-CDMA a layer-specific spreader is applied. As a consequence, in IDMA chip-by-chip interleaving is performed and no distinct

spreading code is used. In IDMA scheme, every user is separated with user-specific interleavers, which are orthogonal in nature. The spreading and the forward error correction are completed by one and the same code. IDMA scheme is known to outperform DS-SS-CDMA scheme in combination with iterative receiver structures, especially for high bit loads. In IDMA systems, different interleavers are assigned to different users. In theory, the user-specific interleavers can be generated independently and randomly. In IDMA scheme, users are solely distinguished by their interleavers. Hence, the scheme employing user specific interleavers for distinguishing user separation is known as interleaver-division multiple-access.

Interleaver in IDMA Scheme

Interleaving is known as a mechanism where the input data rearranges itself so that consecutive data bits are split among different blocks and swapped in a known pattern amongst them. At the receiver side, the interleaved data is rearranged back into the original sequence with the help of de-interleaver. In turbo coding, interleaving is used before the information data is encoded by the second component encoder. The basic role of an interleaver is to construct a long block code from small memory convolutional codes, as long codes can approach the Shannon capacity limit. Secondly, it spreads out burst errors into random errors which may be corrected easily.

Random Interleaver

In this interleaver, the selection of user-specific interleaver is opted to be "random" out of available permutations from the user-specific chips of data. It is well established fact that the random selection of interleaving arrangement patterns out of available large count of interleaving arrangement patterns assures orthogonality between selected interleaving arrangement patterns up to level of utmost satisfaction; however, it cannot be a guarantee for the intended purpose. Limitation of the Random interleaver is that the bandwidth and memory requirement for transmission and storage of all these user-specific interleavers have become major concern in case of large user count, without sacrificing the bit error rate (BER) performance of communication system. Also, it cannot be guaranteed that every random interleaver will have perfect orthogonality among them.

Master Random Interleaver

In some literatures, the researchers have proposed a solution of problems related to bandwidth and

memory requirement for transmission and storage of all these user-specific interleavers in case of higher user count. However the problem of computational complexity of all these user specific interleavers still persists.

Tree Based Interleaver

Though, lot many algorithms of interleavers have been presented by researchers proposing solutions of memory and bandwidth requirements, the problem of computational complexity has been a major concern in all the interleavers. This problem has been solved up to extent in tree based interleaver which presents least complex algorithm for generation of user-specific interleavers along with optimum memory and bandwidth requirements.

Prime Interleaver

Prime interleaver is designed to be based on prime number which gives a user-specific interleaver generation mechanism with lesser time to get it generated and along with minimal consumption of bandwidth required during transmission well similar performance in terms of BER to that of random interleaver. In generation of prime interleaver, the prime numbers are employed as seeds of interleaver. Here, user-specific seeds are assigned to different users. For understanding the mechanism of prime interleaver, let us consider a case of interleaving n bits with seed p .

Firstly, a Galois field $GF(n)$ is considered. Now, the bits are interleaved with a distance of seed over $GF(n)$. For understanding this mechanism of prime interleaver, let us consider a case of interleaving n bits with seed p . First, we consider a Galois field $GF(n)$. If $\{1, 2, 3, 4, 5, \dots, n\}$ are consecutive bits to be interleaved with seed p , then location of bits after interleaving will be as follows:

$$\begin{aligned} 1 &\Rightarrow 1 \\ 2 &\Rightarrow (1+p) \bmod n \\ 3 &\Rightarrow (1+2p) \bmod n \\ 4 &\Rightarrow (1+3p) \bmod n \\ &\dots \\ &\dots \\ n &\Rightarrow (1+(n-1)p) \bmod n \end{aligned}$$

If we have to interleave $n = 8$ bits such that $\{1, 2, 3, 4, 5, 6, 7 \text{ and } 8\}$ and we wish to interleave these bits with seed $p = 3$ then the new location of bit will be as follows:

$$1 \Rightarrow 1$$

$$\begin{aligned}
2 &\Rightarrow (1+1*3) \bmod 8 \Rightarrow 4 \\
3 &\Rightarrow (1+2*3) \bmod 8 \Rightarrow 7 \\
4 &\Rightarrow (1+3*3) \bmod 8 \Rightarrow 2 \\
5 &\Rightarrow (1+4*3) \bmod 8 \Rightarrow 5
\end{aligned}$$

& so on...

Now, the new order of bits will be {1, 4, 7, 2, 5.....}

The bandwidth requirement of Prime Interleavers (PI) is smaller than other available interleavers as now only seed is to be transmitted, in addition to very small amount of memory required at the transmitter and receiver side. This scheme also reduces the computational complexity that occurs in random interleaving scheme.

IDMA Transmitter and Receiver

The block diagram of IDMA system is shown in Fig 1 for K users. The principle of iterative Multi User Detection (MUD) which is a promising technique for multiple access problems i.e. Multiple Access Interference (MAI) is illustrated in the lower part of Figure 1. The upper part of Figure 1 shows the transmitter structure of the multiple access scheme under consideration of K simultaneous users. The input data sequence d_k of user- k is encoded based on a low-rate code C , generating a coded sequence $c_k = [c_k(1), \dots, c_k(j), \dots, c_k(J)]^T$, where J is the frame length. The elements in c_k are referred to as coded bits. Then c_k is permuted by an interleaver π_k , producing $x_k = [x_k(1), \dots, x_k(j), \dots, x_k(J)]^T$. Following the CDMA convention, we call the elements in x_k "chips". At the receiver side, after chip matched filtering, the received signal from the K users can be represented as

$$r(j) = \sum_{k=1}^K h_k x_k(j) + n(j), j=1, 2, \dots, J$$

where h_k is the channel coefficient for user and $\{n(j)\}$ are the samples of an additive white Gaussian noise (AWGN) process with mean as zero and variance $\sigma^2 = N_0 / 2$. An assumption is made that $\{h_k\}$ are known prior to the receiver. For simplicity, we assume binary phase shift keying (BPSK) signalling, i.e. $x_k(j) \in \{+1, -1\}, \forall k, j$ [6].

We use an iterative sub-optimal receiver structure, as illustrated in Figure 1 which consists of an elementary signal estimator (ESE) and K single-user *a posteriori* probability (APP) decoders (DECs). The multiple access and coding constraints are considered separately in the ESE and DECs. The outputs of the

ESE and DECs are extrinsic log-likelihood ratios (LLRs) about $\{x_k(j)\}$ defined as below:

$$e(x_k(j)) = \log \left(\frac{p(y/x_k(j)=+1)}{p(y/x_k(j)=-1)} \right), \forall k, j.$$

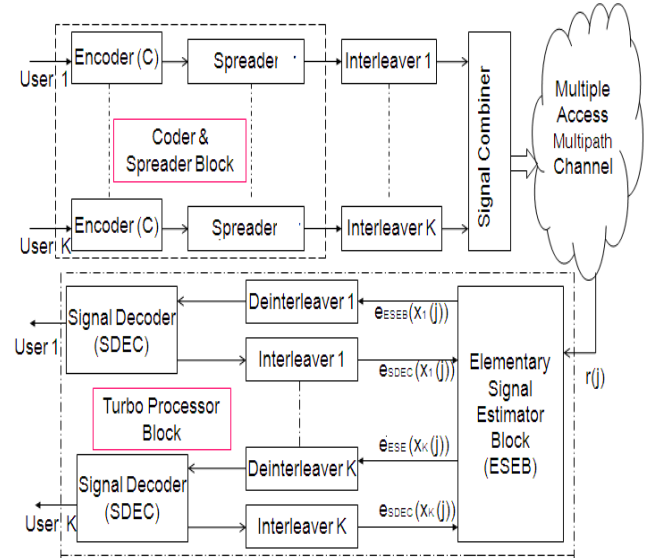


FIG. 1 IDMA TRANSMITTER AND RECEIVER

These log-likelihood ratios are further distinguished by the subscripts i.e., $e_{ESE}(x_k(j))$ and $e_{SDEC}(x_k(j))$, depending upon whether they are generated by ESEB or SDECs.

For specific user k , we can rewrite the equation as

$$r(j) = h_k x_k(j) + \zeta_k(j)$$

where

$$\zeta_k(j) = r(j) - h_k x_k(j) + n(j)$$

is the distortion in $r(j)$ w. r. t user- k . $\zeta_k(j)$ is the distortion (which includes interference-plus-noise) in received signal with respect to user- k .

We briefly list the serial Chip by chip detection algorithm as follows. In a serial scheme, the ESE operations and the APP decoding are carried out user-by-user.

Output of ESEB as extrinsic log-likelihood ratios (LLRs) is given as below:

$$e_{ESE}(x_k(j)) = 2h_k \frac{r(j) - E(r(j)) + h_k E(x_k(j))}{\text{Var}(r(j)) - |h_k|^2 \text{Var}(x_k(j))}$$

The log-likelihood ratio (LLR) output of signal decoder is, $e_{SDEC}(x_k(\pi(j))) = \sum_{j=1}^S e_{ESE}(x_k(\pi(j)))$ $j=1, \dots, S$

These steps will be implemented as per number of iterations defined and users engaged in the systems.

ZIGZAG Coding

Zigzag codes are a family of error-correcting codes. A zigzag code is described by a highly structured zigzag graph. Due to its structural properties of the graph, very low-complexity soft-in/soft-out decoding rules can be implemented. A soft-in soft-out (SISO) decoding is a type of soft-decision decoding used with error correcting codes. "Soft-in" refers to that the incoming data may take on values other than 0 or 1, in order to indicate reliability. "Soft-out" refers to that each bit in the decoded output also takes on a value indicating reliability. Typically, the soft output is used as the soft input to an outer decoder in a system using concatenated codes. Zigzag code exhibits low error floor. The zigzag code is completely parameterized by the pair (I, J) . Graph for zigzag code is shown in Fig 2. Here, white nodes represent information bits: $\{d(i, j), i=1, 2, \dots, I, j=1, 2, \dots, J\}$. Black nodes represent parity bits: $\{p(i), i=1, 2, \dots, I\}$. We call

$$[p(i-1), d(i, 1), d(i, 2), \dots, d(i, J), p(i)]$$

a segment. The parity bits are chosen in this case such that each segment on the graph contains an even number of ones. The code is systematic with coding rate $J/(J+1)$. The encoding process is straightforward. The parity bits are formed progressively as follows:

$$p(1) = \sum_{j=1}^J d(i, j), \text{ mod } 2$$

$$p(1) = \sum_{j=1}^J d(i, j) + p(i-1) \text{ mod } 2, i = 2, 3, \dots, I$$

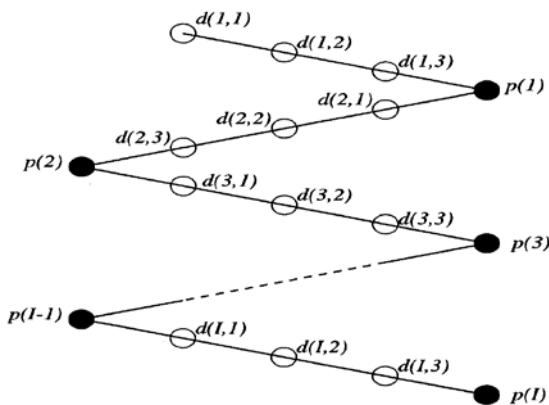


FIG. 2 GRAPHICAL REPRESENTATION OF ZIGZAG CODE

It is noted that the zigzag code is completely parameterized by the pair. The error-correcting capability of the zigzag code itself is weak since it has

minimum distance $d_{\min} = 2$ for any pair (I, J) . However it is very useful in a concatenated construction.

For decoding of zigzag coding, consider that $D = \{d(i, j)\}$ be an $I \times J$ array of information bits and let $P = \{p(i)\}$ be the $I \times 1$ parity vector. Let $Z = (D, P)$ be the $\{+1, -1\}$ modulated codeword ("zero" $\rightarrow +1$, "one" $\rightarrow -1$) and $\tilde{Z} = (\tilde{D}, \tilde{P})$ be the noisy received vector. Let

$$W(a_1, a_2, \dots, a_n) \square \left[\prod_{j=1}^n \text{sign}(a_j) \right] \min_{1 \leq j \leq n} |a_j|$$

And assume that the implementation of the MLA decoding algorithm is as given follows.

- 1). Calculate the forward MLA of the parity bits

$$F[p(0)] = +\infty$$

$$F[p(i)] = \tilde{p}(i) + W(F[p(i-1)], \tilde{d}(i, 1), \tilde{d}(i, 2), \dots, \tilde{d}(i, J))$$

$$i=1, 2, \dots, I$$

- 2). Calculate the backward MLA of the parity bits

$$B[p(I)] = \tilde{p}(I)$$

$$B[p(i-1)]$$

$$= p(i-1) + W((\tilde{d}(i, 1), \tilde{d}(i, 2), \dots, \tilde{d}(i, J), B[p(i)]))$$

$$i = I, I-1, \dots, 2.$$

- 3). Determine the MLA of the information bits as follows:

$$L[d(i, j)]$$

$$= \tilde{d}(i, j) + W(F[p(i-1)], \tilde{d}(i, 1), \tilde{d}(i, 2), \dots, \tilde{d}(i, j-1), \tilde{d}(i, j+1), \dots, \tilde{d}(i, J), B[p(i)])$$

Consider one segment of the code and ignore the operations for taking the absolute value and negation. The evaluation of above equations requires comparisons and one addition. The result can be used for evaluating other equations with one comparison and one addition. The evaluation of equations has performed once for the whole segment. We firstly find the elements among

$$[F[p(i-1)], \tilde{d}(i, 1), \tilde{d}(i, 2), \dots, \tilde{d}(i, J), B[p(i)]]$$

with the minimum and the second minimum amplitudes. This costs $1+J$ comparisons (Notice that the minimum element can be found with only one extra comparison based on the result of equation and

the second minimum requires comparisons). The output of $W(.)$ in above equation is either the minimum or the second minimum value obtained above with the appropriate sign. Finally, the equations require additions per segment.

Receiver Diversity Analysis

MRRC diversity has advantage of producing an output with an acceptable SNR even when none of individual signals are themselves acceptable. In MRRC diversity mechanism, all the branches are used simultaneously for retrieving the best possible signal strength related to receive signal. Each of the branch signals is weighted with a gain factor proportional to its own SNR. Co-phasing and summing are performed for adding up the weighted branch signals in phase.

The block diagram of maximal ratio receiver combining diversity with IDMA scheme is shown in Fig 3. d_k is data of k^{th} user, after encoding and spreading the data is randomly interleaved and termed as 'chips'. Now this chip Signal x_k is sent from the transmit antenna, which will propagate from both the channel.

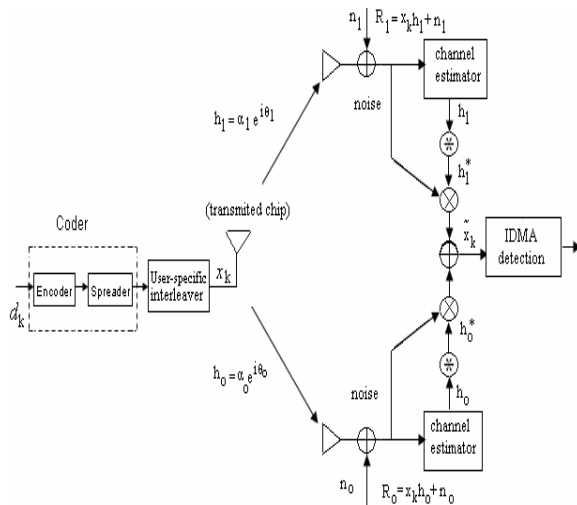


FIG. 3 IDMA SYSTEM WITH TWO BRANCH MRRC ARRANGEMENT

Considering one transmit and two receive antennas architecture for simulation purpose, the channel coefficient between transmit antenna and the first receive-antenna is marked to be h_0 and another coefficient for channel between the transmit antenna and second receive-antenna is denoted by h_1 . The channel can be modelled having magnitude and phase response. So,

$$h_0 = \alpha_0 e^{i\theta_0}$$

$$h_1 = \alpha_1 e^{i\theta_1}$$

The received signal along with noise component at both the receivers is,

$$R_0 = h_0 x_k + n_0$$

$$R_1 = h_1 x_k + n_1$$

where n_0 and n_1 represents the noise and interference at both the receiver separately.

Now the Receiver combining scheme for two branches MRRC is written as, $\bar{X}_k = h_0^* R_0 + h_1^* R_1$

Now this output of maximal ratio receiver combiner can fed to the detector for the proper estimation of transmitted signal x_k .

Performance Analysis of IDMA System with MRRC Diversity Using Random Interleaver with ZIGZAG Coding

For performance evaluation of IDMA scheme with MRRC diversity with IDMA scheme using random interleaver, it is assumed that there is no co-channel and adjacent-channel interference. The simulation is performed in single cell architecture. Also, it is assumed that the channel is a flat fading Rayleigh multipath channel, with BPSK modulations and prime interleaver is used in IDMA system. It is assumed that the user's mobility in the cell is almost negligible. Error correcting code used for simulation is Zigzag Code. Performance of zigzag code in IDMA is discussed in literature.

Simulation Performance

For simulation shown in Fig. 4, data length taken is 128 bits with 20 bits as block length and 16 as spread length. Iterations used for turbo processing is taken to be 18.

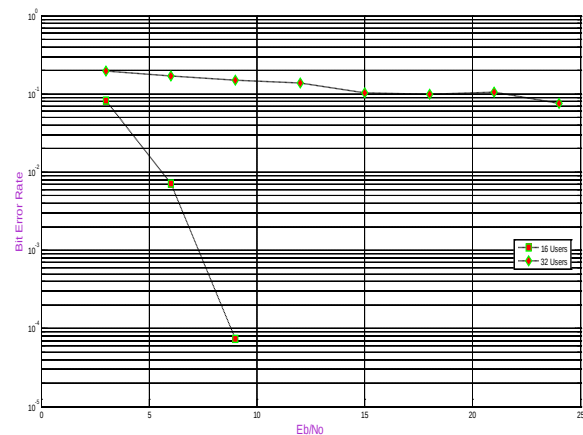


FIG. 4 PRIME INTERLEAVER WITHOUT CODING FOR DIFFERENT USERS

For simulation in Fig 5, data length taken is 128 bits with 100 bits as block length and 8 as spread length. Iterations used for turbo processing is taken to be 13.

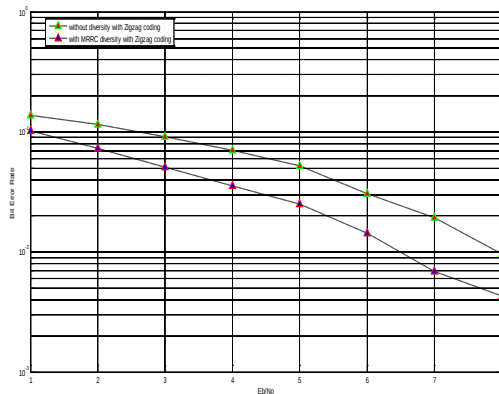


FIG. 5 PRIME INTERLEAVER WITH ZIGZAG CODING WITH AND WITHOUT MRRC DIVERSITY

Conclusion

From above simulations, it is observed that BER increases as the count of users increase in the given communication environment. It is also concluded that there is enhancement in BER performance of iterative IDMA system through MRRC diversity with increase in receiver antenna count at receiver end. Simulation results demonstrate that IDMA system performs better with maximal ratio combining scheme. Therefore, we can conclude that, in space diversity, if the number of receiver antennas or transmitter antennas are increased in receive diversity respectively, the BER performance of the systems improve drastically. However, with increment in receiver antenna and transmitter antenna count, the cost of the system increases rapidly.

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